GEOLOGICAL & GEOMORPHOLOGICAL INPUT INTO TROPICAL COASTAL MANAGEMENT
With special reference to Balikpapan Bay, East Kalimantan

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Geological & Geomorphological Input Into Tropical Coastal Management:
with special reference to Balikpapan Bay, East Kalimantan

by

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EXECUTIVE SUMMARY

1. Although wind and wave energy levels on low latitude coastlines are generally low, these shorelines are very dynamic with potential for volatility due to rapid sediment yield and the characteristically low morphology of the foreshore and back beach areas.

2. The Indonesian situation is even more dynamic due to its location at major tectonic plate margins and, whilst Kalimantan is set back from the subduction zone distortion of late Tertiary rocks indicates active tectonism through to the present day.

3. Balikpapan Bay is a very typical tropical estuary formed along a structural depression and incised into the coastal plateau to at least 45m below sea level during periods of glacially lowered sea levels of the Quaternary.

4. The deformation and heterogeneity of the Tertiary rocks of the catchment have produced a landscape very susceptible to landslips, slides and gullying.

5. Whilst regolith several metres thick has accumulated on the slopes, soils are poor and stoney and only the nutrient recycling processes of the original Dipterocarp rainforest maintained any fertility. Clearing has disrupted this cycle and the majority of soils are now depauperate. Their structural characteristics also encourage gullying.

6. The mesotidal regime of the bay, and strong freshwater inflow appear to have maintained a strong net outflow of water from the bay with good flushing rates which have probably prevented any pollution from the development in the lower estuary intruding up the bay.

7. Longshore drift is from the south and east towards the north and west, though little of the coastal sand appears to cross the estuary mouth. Outflow from the bay will be to the north at most times.

8. There is circumstantial evidence for a continuously rising Holocene sea level in the bay, modern sea level having been achieved in relatively recent times. This may aggravate any problems that result from global sea level rise over the next 100 years from the Greenhouse effect.

9. Naturally high rates of sediment yield in the catchment have been accelerated due to logging, clearing and agricultural practices and are currently very high in areas where development is laying bare large expanses of soil on steep slopes.

10. The mangroves of Balikpapan Bay are the most important part of the coastal system, providing physical protection and stabilisation of fine sediments, nutrient filtering, and playing a pivotal role in the food chain which maintains local fisheries.

11. Whilst some clearing of mangroves may be justified in a scheme of sustainable development what has taken place to date appears haphazard. Acid sulphate soils have led to the abandonment of many. Greater acknowledgement of the problems associated with acid sulphate soils is required in future planning.

12. The major planning/management problems identified in this report are associated with
    1. Accelerated erosion in the catchment
    2. Pollution in the bay from lower bay development
    3. Inappropriate use of the mangrove fringe.

13. Further studies are recommended dealing with high sediment yield, pollution, sea level behaviour and the value of the mangroves.

14. Comparison with other tropical estuaries and bays elsewhere, for which data on the physical processes and planning policies is available is recommended.

1.0 INTRODUCTION

Tropical coastlines of underdeveloped nations are often the focus for settlement, intensively used and intended for further development. Planning and management strategies in the past, and even at the present are often imported from developed countries of North America and Europe. Environmentally these regions located in the temperate zone are very different to the coastlines of low latitudes. Biological and ecological considerations may be taken into consideration by management but as this paper explains, physical processes may also be operating at different levels, passing through different thresholds and presenting managers with novel problems.

Section 2 of this paper examines the major determinants of the physical character and processes of the coastal zone, highlighting the special features of the tropics, especially as applied to Indonesia. Section 3 attempts to characterise the physical processes and development of Balikpapan Bay in East Kalimantan, identifying the most critical issues for planning and management and identifying areas in which detailed investigation may be warranted. Other tropical estuaries for which comparative studies are available are discussed.

2.0 THE MAJOR INFLUENCES AND PROCESSES OF THE TROPICAL COASTAL ZONE

TABLE 1

WHAT DETERMINES THE CHARACTERISTICS OF A COASTLINE AND COASTAL WATERS

1. Global Structure	- tectonic plate centre - tectonic plate margin - rock type

2. Climate	- energy levels
	- transfer linkages
	    - from land
	    - from ocean
	- ecology/biological systems
	
	Inherited elements, related to climate change

3. Relative sea level	- especially during the Holocene - rising relative sea levels - falling or stable relative sea levels

2.1 General

The characteristics which typify the physical features of a coastal zone are numerous but the factors responsible for differentiating, for example, the fjordland coastline of South Island, New Zealand, the Ningaloo coastline of Western Australia or the islands of Indonesia are logical and easily identified into three major areas:

i) the tectonic setting of the region which will determine characteristics such as elevation and available relief, and presence or absence of vertical movements (affecting relative sea level and diagnostic features such as raised reef terraces, drowned valleys etc). Tectonics will also determine the sequence of geological events which have influenced the evolution of the coastline, and the fabric (rock materials) from which the coast is made.

ii) the climate, which in turn controls the processes operating on the coast, including those of the ocean, and their rates of operation. Climate also has a major control on the ecomorphological system found - such as coral reefs, mangroves, salt marsh etc.

iii) the relative sea level change. Sea level is dynamic and constantly changing, sometimes, as during major global glaciation or deglaciation, at rapid rates. However, because of the dynamic nature of the earth resulting from the plasticity and elasticity of the crustal materials (upper earth rheology) sea level behaviour will appear different in different parts of the world and whether sea level over recent times (say the last 5000 years) is static, rising or falling will have profound effects on both coastal processes and land forms.

2.2 Tectonic and Structural Factors

Within the context of global tectonics ‘light’ continental coast ‘floats’ on denser oceanic crust which is formed by volcanic activity along the oceanic ridges of the ocean floor. Like a conveyor belt, oceanic crust moves away from its ridge of origin carrying with it continental crust at rates measured in centimetres per year. Where plates collide oceanic crust is subsumed downward in the subduction zones which form the deepest trenches in the ocean floor. Renewed and violent volcanic activity typifies the subduction zones forming volcanic island arcs. Any continental crust involved in the collision zone remains at the surface perhaps fusing with continental crust from the adjacent plate but experiencing violent vertical movement which can be measured in metres per thousand years. Location of a coastal zone with respect to the sea floor spreading and plate tectonic processes is critical in determining factors such as relief, tectonic stability and even rock type.

At its simplest this can be illustrated by the coastal characteristics of mid ocean volcanic islands, such as Hawaii or the Society Islands of the Pacific. Formed as active volcanoes at what are termed ‘hot spots’ beneath the moving oceanic plate, these islands are formed of mainly basaltic materials. As the ‘hot spot’ location remains fixed, over geological time the oceanic plate moves on, and a new volcanic island forms. In time a line of islands stretches from the active ‘hot spot’. The age of the basalt (determined by radioactive decay) and distance from the ‘hot spot’ provide the data for estimating plate speed.

As the islands move away from their ‘hot spot’, they acquire coral reefs around their fringes. Subsidence also takes place with cooling and erosion cuts into the volcanic core. The end result is the classic sequence of volcanic island/coral reef formation envisaged by Charles Darwin 150 years ago. Islands evolve with fringing reefs then barrier reefs, and finally to atolls. In the Emperor sea mount chain, to the north-west of the Hawaiian islands is the evidence of what happens when atolls continue to move beyond the tropical zone where coral growth can no longer maintain the atoll at sea level, as subsidence continues. These are the Emperor sea mounts.

Rock type is also important for coastal characterisation with some rock types such as granite forming distinctive landscape whatever the climate. Ultimately rock type is resultant upon plate location, acid, light granitic derived rocks of the continents contrasting with the basic heavy basaltic rocks of oceanic plate locations. However, the history of denudation, and sedimentation gives a variety to continental areas not seen in the oceans.

2.3. The Influence of Climate on Tropical Low Latitude Coasts

TABLE 2: HUMID TROPICAL COASTS AND ISLANDS

PROCESS	*LANDFORM*	*MANAGEMENT IMPLICATIONS*
Intense chemical weathering	Deeply weathered soil profiles	*Potential for rapid soil erosion*
High natural rates of sediment yield	Coastal plains, deltas, sand barriers	*Dynamic coastal systems - natural erosion and progradation processes*
Generally low wind & water energy	a) Lack of high beach berm & lack of dunes	*Coastal sand barriers very low lying - not just environmental*
	b) Fragile systems much disturbed by oceanic high energy eg. tropical cyclone, earthquake etc	*Need to acknowledge & plan for occasional extensive damage to parts of environment*
High & specialised biological activity	Coral reefs, mangroves & other eco-morphological communities	*Biological community management - not just environment*

The details of a coastline are determined by the processes of denudation (weathering, erosion, deposition) to landward and the influence of the ocean (waves, tides, physical chemical and biological oceanography) to seaward. Climatic factors are the greatest influence on these processes, and have been discussed in detail by Davies (1972). Low latitude coastlines of the tropics have been discussed by Bird and Hopley (1969) and by Bird (1989). The most important factors, all of which have management implications are:

- intense chemical weathering or decomposition of most rock material in both coastal zone and hinterland
- the production of predominantly fine grained sediments
- a potential for very high sediment yield to the coastline if the vegetation is damaged or destroyed
- generally low wind and wave activity
- specialised highly productive biological activity.

2.3.1 Management Implications of Severe Decomposition

Constant humidity and high temperatures result in many rock constituents being chemically altered, often expanding and forming new clay minerals. Only the most resistant such as silica is unaltered and eventually enters the river system as quartz sand. Deeply weathered slope profiles form rapidly and in stable areas, regolith tens of metres in thickness may form.

Stability of the regolith is maintained by the vegetation cover which also maintains a reasonable level of nutrients in the soils by recycling of organic matter. However the potential for rapid erosion is always present, especially as rainfall is frequently intense. Disturbance of the vegetation canopy from natural, or more commonly man-made sources can result in erosion rates which are normally only moderate, increasing by several orders of magnitude (see below) with streams carrying enormous amounts of sediment to the coast where it is often detrimental to established ecosystems such as coral reefs, mangroves or sea grass beds.

Although many tropical coasts are dominated by depositional processes, wherever rock outcrops it too is subjected to the same intense weathering. Most rock materials are considerably weakened by the process and only at the intertidal level, where the sea actually protects the rock, is hard outcrop found. Vegetation frequently extends down to the intertidal zone. Lacking are the more spectacular cliff landforms such as stacks or arches found in higher latitudes where rock materials are unweathered and mechanically sound enough to maintain such formations.

2.3.2 Sediment Yield and Sediment Type

TABLE 3

DENUDATION RATES FOR TROPICAL HUMID AREAS

1. Total Denudation Rate (tonnes, km^2, year) [1]		
Papua New Guinea (tectonicly active areas)	1000	Chappelland Woodroffe, 1994
North Queensland	17.5 to 703.0	Douglas, 1967, 1969, 1973
Nigeria	5 to 263	Faniton and Jeye, 1983
Various - Rainforest	30 -609	Douglas and Spencer, 1985
Secondary rainforest	20-220	(table 3.5)
Logged	836 - 1924	
2. Suspended sediment rates (milligrams per litre) [2]	**Undisturbed Catchment**	**Disturbed/Cleared**
Nil or minimal rainfall	5 - 20	10 - 50
Normal rainfall event (100mm in 24hrs)	100 - 200	200 - 500
Heavy rainfall event (300mm in 24 hrs)	180 - 260	500 - 19,000

1 See also Pringle (1986) for full review of N. Queensland data

2 Source: Hopley et al 1993. See also Gilmour et al 1982

Over 40 years ago Langbein and Schumm (1958) quantified a general relationship between vegetation and denudation rate. The maximum rate of about 275t.km^2 occurred in semi arid landscapes (300mm precipitation p.a.) with poor vegetation protection. They showed minimum rates of less than 100t.km^2 in forested landscapes with up to 1400mm rainfall. They did not consider the rates in even higher rainfall areas as are found in equatorial forests. Subsequent work (see table 3) has indicated that beyond the point where there can be no further protection given by an already dense protective cover, denudation rates rise again and, if the vegetation cover is removed there is the potential for extremely high rates.

However, whilst rainfall can occur throughout the year Douglas (1973) has shown that 50% of the erosion can take place in as little as 4 days of the year, coinciding with the most intense falls and storms when natural canopy damage takes place and streams overflow their banks. Comparative figures are produced for suspended sediment concentration, for example for the Cape Tribulation area of North Queensland, Australia (Hopley et al 1993). Under natural conditions without intense rainfall, concentrations were only 5-20mg/l. After 100mm in 24 hours concentrations were 100-200mg/l and after a heavy rainfall event of 300mm in 24 hours reached 180-260mg/l. Below severely disturbed areas where road construction was taking place levels were 2 to 5 times higher at lower rainfall intensities but commonly one to two orders of magnitude greater after the intensive event (table 3).

High sediment yield influences coastal landforms with depositional coastlines often dominating the tropics. Such coastal systems are dynamic with potential for rapid progradation and rapid erosion with changing conditions. The greater abundance of fine grained sediments also leads to extensive intertidal mud deposits more often than not colonised by mangroves (Davies, 1972).

2.3.3 Low Wind and Wave Energy

Equatorial latitudes have the lowest incidence of gale force winds and wind speeds are generally very low. Although swell waves can intrude from higher latitudes energy levels are nowhere lower than here.

The end result is that for comparative tidal ranges beach slopes are very shallow, lacking any significant berm feature. For the same reason, accumulation of wind blown sand is minimal with little vertical dune formation. In part this has been attributed to more permanently wet and cohesive sand materials compared to higher latitudes and to the minimal sand trapping capabilities of the low sprawling *Ipomea* sp. communities compared to the more vertical *Spinifex* sp. communities of higher latitudes.

The sand store within and behind the beaches of low latitudes is thus very limited. This encourages more rapid progradation and erosion, reinforcing the dynamic nature of the coastline promoted by high sediment yield, and in direct contrast to temperate latitudes where sandy beaches may be backed by dunes tens of metres high.

However, a coastline normally attuned to low energy conditions may be fragile and very susceptible to any unusually high energy event such as a tropical storm with accompanying surge, or tsunami. Management needs to be aware of return periods and severity of such events and incorporate them into planning and management policy.

2.3.4 High and Specialised Biological Activity

Biological productivity and diversity is greatest in the tropics and this gives rise to specialised eco-morphological communities such as coral reefs, mangroves and sea grass beds which require special management approaches. These communities also play specialised roles in some physical

processes. Coral reefs and mangroves have very important buffering roles. Sea grass acts as a baffling and binding agent for sediment stabilisation and any change in the area or density of a community can have drastic effects on the sediment budgets of adjacent coastlines (see for example Green Island on the Great Barrier Reef, Kuchler, 1978; Hopley, 1982). Mangroves are often said to trap sediment with their intricate root systems and pneumatophores but in fact this is not so (see e.g. Spenceley, 1977). They do however stabilise sediment which is already accreting by the binding action of their high biomass rootlet system below the surface.

2.4 Relative Sea Level Change

Because of the dynamic nature of the earth's crust sea level at any location is dependant not only on the volume of water within the ocean basins (eustasy) but also on the elasticity and plasticity of crustal materials and the loading and unloading stresses put on them (isostasy). These processes are superimposed on vertical tectonic movements especially near the plate margins, and mid oceanic ridges. Cooling subsidence also takes place in the ocean floor as it moves away from its source mid-oceanic ridge.

All these processes can result in vertical movements of the land which may be measured in metres per thousand years. Many coastal characteristics and processes are characterised by such movements (see Hopley, 1985 for discussion).

Globally the most rapid vertical movements are found close to the margins of the tectonic plates. However, these are superimposed on a pattern which was largely determined by the last major glaciation. 18,000 years ago major ice centres up to 2.5km thick occurred over North America and north-western Europe with greater ice thickness also over Greenland and Antarctica. As ice has disappeared or thinned over these areas uplift of >500m has occurred and current uplift still has a maximum rate of 9mm.yr. However, a compensating downwarping is occurring in a 2000km band around the deglaciating isostatic rebound areas with up to 7m of subsidence occurring in the last 5000 years (Walcott, 1972). The eastern coast of the USA and the North Sea area of Western Europe experience this maximum subsidence rate. At greater distance away from the glaciated areas stability or slight uplift may prevail, especially across the southern hemisphere.

However, even on this general pattern are local effects. Continental shelves which were dry at the glacial maximum now have the loading of 150m of water, sufficient to cause depression of the shelves and compensatory uplift of adjacent continents. As the fulcrum between uplift and subsidence may be either side of the present coastline this factor may also be affecting sea level behaviour in different directions in different places.

2.4.1 Some Management Implications

The direction and rate of relative sea level movement at any location needs to be determined locally as it will have very specific implications for management. Two examples are given here. Firstly global sea level rise as the result of the Greenhouse Effect at best estimate will be about 0.5m in the next 100 years and integrated coastal zone management with some specific action is advocated to counteract what may be drastic economic, social and ecological results (IPCC, 1996). Already sea level over the last century has risen about 12cm (Gornitiz and Lebedeff, 1987; Barnett, 1988). Obviously the way in which local sea level is behaving may either reinforce or negate the Greenhouse rise. Areas identified as having a pattern of relative sea level rise whether due to isostatic or tectonic reasons obviously will require more urgent planning and management responses.

The problems associated with coastal erosion even more widely illustrate the need for coastal managers to understand the physical processes operating on coastlines. The direction in which a coastline is moving (eroding or accreting) is the net balance of sea level movement and sediment supply (table 4). Recognition of the root cause of erosion is needed to illicit the most appropriate response (table 5). In areas such as the central east coast of the USA or the North Sea basin of Western Europe measures such as groynes, minor protection works, re-vegetation of dunes or artificial replenishment of sand may be at best short term stop gap solutions in areas where there is a long term subsidence problem upon which global sea level rise is being superimposed. If protection is deemed necessary rather than retreat, (and this would be expected in areas where such high economic and social values exist) then the measures to be used or already in use will be massive and expensive. The dyke system of the Netherlands, and the Thames barrage illustrate this.

Elsewhere, where the problem may be a starvation of sediment then the secondary level responses may be appropriate. Particularly important is the identification of a human cause of erosion especially if counter measures can be put into effect.

TABLE 4

COASTAL EROSION

1. Rising sea level Greenhouse rise	- eustatic - isostatic - hydro-isostatic
2. Subsiding land	- tectonic - isostatic (glacial, sediment) - human activities

3. Changing sediment yield	- climatic
	- river diversion
	- mans activities
	    - dams
	    - sand mining
	- coastal engineering

4. Changing climate	- wind strength - wind direction

TABLE 5

MANAGEMENT RESPONSES TO COASTAL EROSION

Cause	Short to Medium term	Long term
Rising Sea level/Subsiding land - geological causes	Coastal Defence e.g. walls, tetra pods + other hard and soft engineering solutions	Retreat with Social Planning or V. Expensive Protection e.g. dykes - Netherlands Barrages - Osaka London
Rising Sea level/Subsiding land - human induced	Coastal Defence	Fix the man made cause e.g. groundwater pumping - Bangkok Greenhouse gas abatement
Loss of Sediment - natural	Artificial sand replenishment Coastal revegetation and other protection works	Retreat or Expensive Protection
Loss of Sediment - human induced	Artificial replenishment Coastal revegetation	Fix the man made cause e.g. river dams coastal obstructions

Knowing cause may determine management solution. In addition it will indicate if problems will be intensified or not by Greenhouse Sea Level rise.

3.0 BALIKPAPAN BAY

These comments on the geology and geomorphology of Balikpapan Bay and assessment of management implications are based on a short 10 day period of reconnaissance in February 1999. Available literature, including the 1:250,000 Systematic Geological Map of Indonesia (Balikpapan Sheet 1814, 1914) has been sourced in the Proyek Pesisir Office in Balikpapan. A valuable though general background is provided by McKinnon et al (1996). Field visits included ground survey incorporating a 200km traverse around the entire bay, boat survey to the head of the bay and a two hour overflight by helicopter. Nonetheless the conclusions reached here must be regarded as tentative and further investigations are recommended.

3.1 Geological and Geomorphological Characterisation of the Bay

3.1.1 Geological evolution

Although the island of Borneo, part of the Sunda Platform of south-east Asia, is set back from the active subduction zone of the southern Indonesian archipelago from Sumatra to Irian Jaya, it is an active area which has seen some severe deformation of even late Tertiary rocks which can have dips of up to 70^0.

The Balikpapan-Samarinda region is part of a Tertiary Basin with up to 9000m of sediments which has been infilled by deposits from the older parts of Borneo to the north and west. Older Tertiary
sediments underlie the Balikpapan Bay area but surface geology is composed of late Tertiary Miocene and Pliocene sediments. These were laid down from early Miocene times in a deep offshore environment but due to a worldwide lowering of sea level 25 to 30m.y. ago due to both ocean basin enlarging and initiation of glaciation in Antarctica (and later Greenland), and to local uplift, Upper Miocene to Pliocene formations are in shallowing, offshore, littoral and deltaic environments possibly similar to today. Deformation of the sediments producing north-east to south-west fold structures continued throughout the depositional period and subsequently.

Quaternary fluvial, estuarine and coastal deposits are found around Balikpapan Bay and along the coast to the west. They are shown as Holocene on the maps but around Petung large coastal sand bodies appeared to be older, possibly late Pleistocene in age, deposited as coastal dunes in a drier climate (as is suggested in MacKinnon et al 1996). However, most of the Pleistocene appears to have been dominated by erosion. Accordance of ridge top levels (c.100m to the east and 45m

to the west of Balikpapan Bay) suggest a period of planation during which a south flowing drainage system including the Sepaku River and Balikpapan Bay and even more strikingly the Mahakam River to the north cut obliquely across the regionalstructural trend. Incision, for example in Balikpapan Bay, was to at least 46m (the maximum recorded depth in the lower estuary) probably cut during glacially lowered sea levels. According to the German Provincial Atlas (Geomorphology, Map 4, page 30) the alignment of Balikpapan Bay is produced by a subrecent morphotectonic depression. The difference in ridge tops highlights either side of the bay may indicate differential rates of movement.

3.1.2 Rock types

Rock types of the late Tertiary Pamaluan, Bebulu, Pulaubalang, Balikpapan and Kampungbaru Formations are complex, fragmented and some cases unconsolidated. Beds are normally very thin and consist of sandstones, siltstones, claystone and shales, with interbedded limestones, marls, lignite and coal. On weathering they can form regolith up to several metres thickness but the soils are extremely poor and stoney. The original rich Dipterocarp lowland forest has been maintained purely by nutrient recycling and the soils are generally unsuited for agriculture.

They are also highly erodable. The provincial atlas classifies most as acrisols and arenosols, recognised as erosion endangered and characterised by extreme stoniness with intensive headward extension of drainage systems on cleared land. Vertical structures in the soils which were examined in the field aid gully erosion. Numerous slope failures were also observed, including on roads built above steep slopes. Slides and rotational slips are aided by the complex lithology, slip planes forming above impermeable rock layers which become saturated after rainfall, and by steep dips.

Overall the Balikpapan Bay area is one which is highly susceptible to accelerated erosion (see below).

3.1.3 Geomorphological evolution and processes

Balikpapan Bay is a very typical tropical estuary. It formed as a dendritic fluvial system graded to well below present sea level during glacially lowered Pleistocene sea levels. The course of the channel, since infilled, almost certainly extends south across the continental shelf. Within the bay it is incised at least 40m, probably more than 50m. The rising Holocene sea level has drowned the valley to form the present estuary. The regional Holocene level curve, as

characterised by Tjia and his colleagues over a number of years, has a higher than present level achieved about 6000yrs ago and a fluctuating fall since. There is no evidence in the Balikpapan area for such a higher sea level. Indeed there is evidence to suggest that locally modern sea level has been reached relatively recently. It is not surprising that in such a tectonically active area there should be departures from the regional sea level pattern.
The evidence includes:

- lack of higher and even extensive older shoreline features such as beach ridges
- relatively small amount of infill of the estuary in spite of obviously high erosion rates
- deeply weathered profiles on islands and headlands within the Bay extending right down to the intertidal zone with no evidence of any stripping above this.

Management implications of this conclusion include an increased risk for Balikpapan Bay and all its structures from global sea level rise in the not too distant future (see below).

As indicated coastal deposits are not extensive and largely absent to the east of the bay mouth. To the west is a prograding foreland area (Tanjung Jumelai), partly deltaic but also with a distinctive Holocene barrier along which most of the coastal villages are located. As indicated above, further inland may be older, Pleistocene coastal deposits in the form of red sand bodies.

Main coastal drift appears to be from west to east as indicated by the shallow bar extending across the mouth of the bay from Tanjung Jumelai. This is part of a poorly developed ebb tide delta at the mouth of Balikpapan Bay. Poor development is probably due to the continuously rising sea level but the lack of a flood tide delta inside the bay suggests that even on the incoming tide there is only minimal flow up-estuary. This needs confirming by oceanographic surveys but may explain the relatively good condition of the middle and upper estuary in spite of the development, industrialisation and pollution of the lower estuary.

3.2 Factors Related to Accelerated Erosion

After direct industrial and urban pollution effects the greatest dangers to the environmental credentials of Balikpapan Bay are those associated with accelerated run-off. Denudation/sedimentation rates have probably always been high as the natural conditions of high rainfall, steep slopes and friable soils have always been present. Only estimates can be made of pre-disturbance rates but based on published data, figures in the upper scales given in various formats in table 3 may, at least, be of the right order of magnitude for Balikpapan Bay. During reconnaissance of the catchment, without any immediate rainfall, the majority of streams appeared to be very turbid.

Accelerated erosion not only degrades the catchment area but also has direct impacts on the coastal environment. Freshwater sediments and nutrients may all be regarded as pollutants. Vegetation clearance results in 'quick flow' response during rainstorms, with less water being maintained in the vegetation and soil systems and sharper flood peaks. Reduced salinities are detrimental to many parts of coastal ecosystems including coral reefs, mangroves and sea grass beds. Brackish water communities such as *Nypa* sp. palm may expand at the expense of mangroves. Reconnaissance observations suggest that this may already have happened in the lower reaches of the Sepaku River.

Increased sediment yield has a variety of effects, from completely smothering ecosystems such as coral reefs, mangroves or sea grass beds to reducing the amount of light reaching bottom communities. The literature suggests that in environments such as the Balikpapan catchment, only limited logging operations (including forestry tracks) may increase sediment yield three-fold whilst clear felling may result in a ten times increase (Gilmour, 1977).

3.2.1 Major influences on the accelerated erosion rates within the Balikpapan Bay Catchment

1. Vegetation loss.

Very little of the original lowland rainforest remains within the catchment and that which does appears to have been heavily logged. During logging operations, which are continuing in parts of the catchment increased sediment yield has undoubtedly taken place, but where logging is no longer taking place the secondary regrowth is probably providing as effective a ground cover as the pristine vegetation. Determination of current logging areas is thus important in estimating current sedimentation rates.

Large areas of the upper catchment have a tall grass cover and this too appears to provide a reasonable protective cover in the state it was observed during the reconnaissance. However, such grass during dry spells is very susceptible to fire after which its effectiveness may be sharply reduced. The status of these tall grasslands and the frequency of fires after dry spells (1997?) may need to be assessed.

Agricultural areas appear to be very prone to erosion. Upland dry farming was observed in many areas with little attempt at introducing soil conservation measures. Examples of crop rows trenching up and down the slopes (rather than along contours) and much bare ground between crops were widely observed. A soil conservation programme could do much to reduce sediment yield from these areas.

Probably the most erosion prone areas were observed around Balikpapan city. These included totally bare areas in which the soil had been bulldozed even on quite steep slopes in preparation for port and industrial development. Possibly even more extensive were areas totally cleared for suburban housing and new roads. The amount of gullying observed in these areas suggested the land had lain bare for some time. Some controls on developers practices would appear warranted.

2. Relief

Although the total relief within the catchment is not great (500m) away from the coastal plain to the west of the bay there is very little flat land. Slopes are often short but steep (>30^0) and ridge tops narrow. Only valley bottoms lack sufficient slope. These are prime agricultural areas with a large proportion already under paddy rice.

3. Soils

As previously noted the soils are very poor once the vegetation is removed and nutrient recycling is disrupted. Whilst they are not moisture retaining, impervious subsoils in some areas appear to create numerous slip planes for soil and slope failure. Vertical columnar type structures (cracks) were observed in a number of exposures and these will accelerate gully erosion once vegetation is cleared. Because of the heterogeneous nature of the parent rock materials no broadscale soils pattern was observed but the observations of a soil scientist could be useful in identifying soils which are particularly erosion prone. Based on the regional soil survey carried out by German scientists in the 1980's a generalisation of the soils may be:

On Quaternary deposits of the coastal plain - fluvisols and gleysols which generally have low erodibility

On the Pliocene deposits of the southern part of the catchment - acrisols, soils with alluvial clay and strong base depletion and apparently very susceptible to gully erosion and slippage

On the older Miocene rocks of the northern part of the catchment - arenosols, which are sandy and rocky with susceptibility for sheet wash.

4. Rainfall

Annual rainfall totals at Balikpapan are variously reported as 2583mm (German atlas) or 3060mm (Balikpapan Yearbook). Minimum monthly totals are in October (about 1180mm) and maximums in May (about 370mm). Higher and more intense totals may be expected in the upper catchment. These totals are sufficiently high to produce significant run-off. Under natural vegetation the proportion of run-off expected would be between 50% and 60%. Where vegetation has been cleared or modified this would increase, hence increasing the erosion potential.

5. Human structures

Most human structures including roads and buildings have a tendency to increase the amount of run-off and concentrate it into a shorter (more peaked) period. This was certainly noted around Balikpapan where engineered drainage adjacent to many structures appeared inadequate and thus aggravating the erosion problems.

Even where roads are unsealed they may still contribute significantly to accelerated erosion for reasons outlined in Table 6.

TABLE 6

CAUSES OF ACCELERATED EROSION FROM ROADS IN RAINFOREST CATCHMENTS

1.	Removal or reduction of the protective vegetation cover
2.	Destruction or impairment of natural soil structure and fertility
3.	Increased slope gradients cause by construction of cut and fill slopes
4.	Decreased infiltration rates on parts of the road due to compaction
5.	Interception of the subsurface flow by the road cut slope
6.	Decreased sheer stress, increased sheer stress or both on cut and fill slopes
7.	Concentration of generated and intercepted water, resurrected groundwater and storm flow which may overload natural channels and initiate a cycle of bank cutting

(Bullard, 1966; Megahon, 1977; Sim, 1984)

3.3 Coastal and Estuarine Processes Significant for Management

Balikpapan Bay is a very typical tropical estuarine system and appears to have relatively simple and predictable geomorphological and oceanographic processes though the quantification of these may need determining.

3.3.1 Longshore Drift

All morphological evidence suggests that the dominant longshore drift is south and west to north and east. Balikpapan Bay itself is a trap for north-eastward moving sediment which accumulates around Tanjung Jumelai, whilst the shores to the east receive very little sediment. The Balikpapan catchment is providing very little if any sediment to the open coast. Any freshwater plume will normally flow east and north from the estuary mouth. Any pollution carried from the industrialised and urbanised area will therefore follow the same pathway. This should be considered in the location of mariculture or any other activity for which water quality is critical.

3.3.2 Physical Oceanography

Balikpapan Bay is mesotidal (range about 3.0m) with a mixed to semi diurnal regime. Together with the freshwater input to the bay, as previously mentioned, this appears to produce an efficient flushing of the bay and a strong net outflow which has helped to prevent the pollutants of the lower estuary intruding any distance upstream. Further studies should be undertaken to accurately determine the flushing time and directions of flow especially in the middle to lower basin. In order to maintain the water quality of the majority of the bay, any further industrialisation and development should take this data into account. From current observations limitation of such development to the lower part of the bay around Balikpapan and especially on the eastern shoreline would appear warranted. Competition for land space in this restricted area may be partially overcome by a rationalisation of land-use which removes industries and activities not requiring water-front land from the foreshore areas.

3.3.3 Sea level rise

It has been suggested above that the geological trend for sea level in the Balikpapan area may be upwards and that in the next 100 years this will reinforce the global sea level rise consequent upon the Greenhouse Effect. This could have serious consequences for the many low lying areas around Balikpapan Bay. Already in most parts of Australia an 0.5m rise in sea level is incorporated into foreshore engineering design principles, in addition to flood and storm surge data (which are probably insignificant for Balikpapan). It is suggested that the Balikpapan Municipality and the Pasir Regency governments be approached to consider similar future planning. In addition an assessment of areas of potential inundation and the social, economic and environmental effects (e.g. identification of floodable hazardous waste sites etc.), would be a valuable planning exercise.

Changes will also take place to the natural environment with mangroves in most parts of the bay able to migrate landwards, in some instances at the expense of the currently expanding *Nypa* palm communities. Chappell and Woodroffe (1994) have also predicted changes to the physical oceanography of tropical estuaries with a sea level rise. The total tidal prism is predicted to increase, with an increase in flow velocities. Ebb flow velocities in particular would be increased, further enhancing the ebb dominance of estuaries such as Balikpapan Bay with obvious advantages for flushing of pollutants.

3.3.4 Mangroves

The mangrove fringe is the most important part of the Balikpapan Bay ecosystem. It plays a pivotal role in the food chain and nutrient cycling within the bay and thereby has an integral role in local fisheries. The importance of mangroves in stabilising the fine sediment which enters the bay has already been emphasised. However, in addition, because of their position between the river system and the marine waters, the mangrove forests also serve as efficient filters of nutrients and other human derived contaminants. Maintenance of a healthy mangrove fringe should be the first aim of management within Balikpapan Bay. Further studies to determine the biodiversity of the mangrove forests should be undertaken but more than 30 species may be expected

The major management problem of the mangrove areas would appear to be clearance for fish ponds. Whilst such use of the mangroves may be justified within a sustainable development management plan, there appears to be widespread abandonment of ponds shortly after they have been constructed due to contamination from acid sulphate soils. Acid sulphate soils are formed when iron pyrite ($Fe\ S_2$) within the sediments is exposed or the water table is lowered, resulting in oxidation and formation of sulphuric acid. This reacts with the clay minerals in the soil and increases levels of dissolved aluminium and iron. These in turn form compounds very toxic to fish and promote further acidification. Not only are the fish and crustaceans within the ponds affected, but drainage water from them also affects the wild stock. A review of the problems of converting mangroves to fish ponds and some rehabilitation methods is given in Brown (1977).

An important target for the management of Balikpapan Bay is the determination of the extent of the problem through a systematic mapping programme. Appropriate choices for land-use may then be made.

3.3.5 Coral Reefs

Three small patch reefs are located just to the west of the mouth of Balikpapan Bay, confirming that the major outflow for the bay is to the east. The status of these reefs is not known but if still in reasonable condition may serve as an indicator of the health of bay waters.

4.0 CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

4.1 Management Problems

Balikpapan Bay is a dynamic tropical estuary which has historically received a high sediment load from its catchment due to tectonic factors, rugged relative relief, erodable soils and high rainfall. However, widespread logging and clearing of the catchment, use of poor agricultural practices, industrialisation and urbanisation have greatly accelerated the erosion rates and this is the greatest problem for management. Catchment management is essential for the continued health of the bay, which is, as yet, in a reasonable environmental state over much of the middle and upper reaches in spite of the degree of development and obvious pollution around the municipality of Balikpapan. Pollution inside the bay is probably alleviated by reasonable rates of flushing. Nonetheless man-made pollution is probably the second most important management problem for the bay. Third are problems related to the over-use or inappropriate use of resources. Further information is required on fish stocks and on the utilisation of mangroves especially in relation to the distribution of acid sulphate soils around the bay. Finally, the bay appears to be susceptible to global sea level rise. An assessment of the risk is urgently required.

4.2 Further Studies

Crystallization of these problems and identification of the most appropriate management strategies will be greatly aided by further studies. The extent to which these can be carried out will depend on budget, and availability of expertise and technology. However, the following studies may help to elucidate some of the questions raised in this report.

4.2.1 Studies related to sediment yield

i) Detailed mapping of soils with special emphasis on erodibility

ii) Development of a GIS formatted catchment erodibility index as outlined in Appendix A.

iii) Climatological analysis of available meteorological data to identify parameters related to rainfall variability, including the frequency of 'extreme' events and identification of 5 year, 10 year and 50 year return periods for specific rainfall intensities.

iv) Identification of present logging areas within the catchment and logging practices.

v) Assessment of current agricultural practices by a soil conservationist to identify ways in which erosion may be reduced from agricultural land. This may mean suggested changes in current land-use practices.

4.2.2 Studies related to bay pollution

i) Determination of the physical oceanography of the bay, in particular the amount of run-off received, current patterns and flushing rates.

ii) Determination of the chemical and biological oceanography of the bay to identify present levels and areas of pollutants and other characteristics such as eutrophication.

iii) Analysis of bay sediments to determine rates of sedimentation and the extent of past pollution. It is suggested that the use of a gravity corer to extract cores up to 1m long would be appropriate. Three transects across the bay (upper, middle and lower) and a further transect along the length of the bay would provide sufficient data to identify the extent of intrusion of any industrial pollution, and the rate of sedimentation in different parts of the bay. Dating may be possible through the use of 210Pb and pollution indicators would include mercury and other heavy metals. However, a programme would have to be devised specifically for Balikpapan Bay after pilot studies.

4.2.3 Studies related to mangroves

i) Determination of the species richness of the bay.

ii) Determination of the extent of clearing within the bay and the areas in which fishponds have been abandoned due to acid sulphate soils.

iii) Mapping of acid sulphate soils (note a small acid sulphate soil testing kit costing only A$30 is available from the Townsville City Council, Queensland which is simple to use and provides reliable data).

4.2.4 Studies related to sea level

i) Determination of the local relative sea level curve and local subsidence rates. It is suggested that radiocarbon dating of basal mangrove peats (deposits immediately above the underlying bedrock so as to avoid problems of compaction) will provide a reliable data set.

ii) Social and economic surveys to determine the risk of 0.5m sea level rise.

4.2.5 Comparison with other estuaries

Much may be gained by studying the dynamics, uses and planning strategies of other estuaries systems. A number of these are listed in Appendix B.

4.3 Concluding Comments

Balikpapan Bay is a tropical estuarine system in which the mangroves play a vital role. They are, however, under threat both directly through clearing and cutting, and indirectly through enhanced sedimentation and pollution. The bay is an important resource at the artisanal level. The major task of planning and management will be to maintain a balance which allows sustainability of all resources for all stakeholders. The key to success will lie in persuading all stakeholders, who have very different levels of empowerment, that any planning initiatives are beneficial to all.

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APPENDIX A:

SUGGESTED RAPID ASSESSMENT METHODOLOGY TO IDENTIFY SENSITIVE EROSION AREAS IN THE BALIKPAPAN BAY AREA.

This review identified vegetation cover, slope, soil type, rainfall and the density of human structures as the most important factors in determining sediment yield in the Balikpapan Bay area. They are not of equal importance. The literature suggests that given the range of other variables found in the Balikpapan catchment area, vegetation is of greatest importance, followed by slope and of about equal importance soil type, rainfall and man made structures. This suggested methodology weights these factors to produce an index number of erodibility as potential erodibility based on the $1km^2$ grid squares of the topographic map. It should be able to use G.I.S. stored data and provide information for input into a G.I.S. The purpose is to identify areas which may already be contributing to the high sediment yield into the bay and areas which have the potential to do so. Priorities for management responses may thus be highlighted.

An index number (low for low erodibility, high for high) is calculated for each $1km^2$ grid square. It is the sum of:

1. Vegetation cover index number on a scale of 1 to 20 based on a qualitative assessment of the protection given by the vegetation to the soil surface. Suggested points on the scale are based on published sediment yield figures from around the world and should have a reasonably linear relationship

    20 - Bare soil
    18 - Urban or developing area with many bare patches or area currently being logged
    16 - Agricultural land, minimal protection at some seasons
    14 - Suburban land, with gardens etc.
    12 - Tall grassland with forest patches
    8 - Partially logged forest, small clearings, forestry tracks
    4 - Secondary regrowth forest
    1 - Pristine forest, including tidal forest

2. A slope index number on a scale of 1(flat) to 10 (steep) based on relative relief (difference between highest and lowest point) within the $1km^2$ grid squares. The suggested scale may have to be modified with greater familiarity with the Balikpapan Bay area

10 -	relative relief	>250m
9 -	“ “	200 to 250m
8 -	“ “	165 to 200m
7 -	“ “	125 to 165m
6 -	“ “	75 to 125m
5 -	“ “	50 to 75m
4 -	“ “	25 to 50m
3 -	“ “	10 to 25m
2 -	“ “	5 to 10m
1 -	Flat, relative relief	<5m

3. A soil index number between 1 (low potential for erosion) to 5 (high). This may be the most difficult data set to acquire, but based on reconnaissance observation the following may be a guide.

    5 - thick friable soils with vertical structures overlying dipping thinly bedded and impermeable subsoils. May already have evidence of slips and slides.
    3 - soils with higher clay content, more cohesive and with better drained subsoil.
    1 - alluvial soils, well drained.

4. A rainfall index number between 1 and 5 reflecting the variation of annual totals within the catchment. A suggested scale is:
    5 >3500mm
    4 3000 to 3500mm
    3 2500 to 3000mm
    2 2000 to 2500mm
    1 <2000mm

5. An index number based on the density of human structures in the area which will concentrate run-off possibly also adding pollutants. This number may correlate with the vegetation index number which it will reinforce.
   A suggested scale is:
    5 - heavily urbanised or industrialised
    4 - suburban land with dense road network
    3 - rural settlement nucleated (villages)
    2 - some roads, scattered rural settlement
    1 - no human structures

The range of the erodibility index will thus be between 5 (low sediment yield, low risk) to 45 (catastrophic!). The attached photographs show a range of environments and suggested indices for them. Some refinement of the system may be required based on local knowledge and experimentation.

APPENDIX B:

STUDIES OF TROPICAL ESTUARIES AND BAYS WHICH MAY HAVE RELEVANCE FOR BALIKPAPAN BAY.

Although this author is familiar with a very large literature on coastal geomorphology, coastal processes and coastal management surprisingly little of this is relevant to the tropical location of Balikpapan Bay. The majority of detailed physical process studies are for temperate estuaries and the important and different roles played by the mangrove fringes in the physical, chemical and biological processes of tropical estuaries limits the value of these studies. In part this is due to the vast majority of such tropical systems being found in under-developed countries. A similar situation exists in relation to coral reefs and their management and here the understanding and management of that ecosystem has evolved from the developed nations such as the United States and Australia. However, for both coral reefs and mangrove dominated estuaries the pressures of population and resource use are orders of magnitude lower than in the developing nations such as those of South-east Asia. Adoption of any planning and management strategies must take this into account.

This review first examines studies of physical processes in tropical estuaries which may be useful for the Balikpapan Bay project, then identifies appropriate comparative areas where planning and management has been attempted. Only the major conclusions from these studies are given, but the most important references are provided for further study. In some instances copies of these are being forwarded to the Proyek Pesisir office.

PROCESS STUDIES

The majority of estuarine studies relate to temperate locations where the saltmarsh intertidal vegetation plays a very different role to the mangroves of tropical estuaries and where the sedimentation dynamics of the catchments also differs. It is considered that the most relevant literature, therefore, comes from northern Australia.

1. Dynamics and Evolution of Macrotidal Estuaries of Northern Australia.

A major review of this topic is provided by Chappell and Woodroffe (1994), building on a series of important studies relating in particular to the Daly, Elizabeth, Adelaide, Mary and South Alligator Rivers and some of the major estuaries of the northern part of Western Australia, the major references to which are given below. Some make comparisons with other estuarine systems in South-east Asia. The physical processes of sedimentation and their rates are discussed in the majority of these references. The role played by mangroves is emphasised. The likely effects of sea level rise are reviewed by Chappell and Woodroffe (1994).

However, some important differences exist between these estuaries and Balikpapan Bay including:

- northern Australia is tectonically very stable
- the climate is highly seasonal
- sediment yield is generally very low (5 to 15t.km^2 .yr)
- the relative sea level history shows modern sea level being achieved 6000yrs ago

Nonetheless these are probably the most useful references on geological evolution, and geomorphological processes.

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2. Missionary Bay, Hinchinbrook Island, North Queensland

Missionary Bay is located at the northern end of Hinchinbrook Island. It is a broad shallow bay characterised by extensive development of mangroves. It has been the site of major mangrove ecological and process studies by the Australian Institute of Marine Science for a number of years and the evolution of the estuary was previously discussed by Grindrod and Rhodes (1984). The adjacent 44km long Hinchinbrook Channel, effectively an open estuary has also figured in their studies.

In terms of studies of the general ecology of mangrove swamps, their primary productivity, nutrient production and export, role of macro and micro fauna and physical oceanographic processes of flushing and trapping, no other area has been investigated as intensively. The literature produced by the AIMS mangrove group is very large, most of it appearing before 1995. A full publication list is attached, much of it dealing with Hinchinbrook Island, and this should be the first source of any information dealing with the trophic structure, productivity and processes within estuarine mangroves.

A further advantage of the Hinchinbrook Island site is that it has been incorporated into a regional coastal plan (Queensland Department of Environment, 1996). Although this is directed mainly at recreational use and the area has none of the heavy uses of Balikpapan Bay, some of the strategies used, and the philosophy behind them, including zoning (see attached figure) will make an interesting comparison with the East Kalimantan site.

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PLANNING AND MANAGEMENT OF TROPICAL ESTUARIES AND BAYS

There are many examples from tropical estuaries and bays of development without planning, development with poor or inappropriate planning or planning and management strategies purely for single purposes such as conservation or fishing. Examples of management for multi-uses particularly in areas of heavy use are far rarer. The examples quoted here are probably not exhaustive, but it is believed that each displays experience which could be useful for Balikpapan Bay. The most appropriate are discussed first.

1. Port Curtis, Gladstone, Queensland, Australia

From both the environmental, and developmental view Port Curtis on which the port and industrial city of Gladstone is located is an excellent analogy to Balikpapan Bay. The estuarine configuration, however, is different, the bay being more open, only partially closed from the sea by Facing Island, but many parts are sufficiently sheltered to maintain a mangrove fringe, with several estuaries entering the bay and, to the north, is a narrow mangrove lined channel called The Narrows separating Curtis Island from the mainland (see map).

The Port Curtis area has a population of 40,000 people. Gladstone is the largest port in Queensland and has major heavy industry including the world's largest aluminium refinery, chemical and cement industries, and the largest coal powered power station in Queensland. It is also a major coal exporting port. An oil shale industry is proposed. Simultaneously Gladstone is the southern gateway to the Great Barrier Reef.

There are obvious conflicts of use in the Port Curtis area and whilst there is some environmental awareness in both the Gladstone City Council and the Gladstone Port Authority, no integrated planning has taken place. Concerns for the environment resulted

in a symposium being held in 1995 in which the issue of threats to the mangroves was discussed (Hopley and Warner, eds. 1996). A copy of the proceedings will be supplied to the Proyek Pesisir office.

The Port Curtis area is certainly not a blue print for Balikpapan Bay, but the scale and pressures involved have many similarities and studies of the experiences from Gladstone may be enlightening.

REFERENCE:

Hopley, D. & Warner, L (eds.) 1996. *Mangroves - a Resource under Threat. An Issue for the Central Queensland Coast.* Proceedings of a Symposium held Oct. 1995. Austr. Mar. Sci. Consort., 95pp.

2. Trinity Inlet, Cairns

Trinity Inlet, Cairns has already been identified by Proyek Pesisir as a possible comparative study for Balikpapan Bay. A summary outline of the plan (originating in 1991) is attached.

Although Trinity Inlet has some excellent guidelines for Balikpapan Bay there are some drawbacks. First, the inlet is the abandoned mouth of a river and today has only a very limited catchment with little inflow. The whole scale of the catchment is also much smaller and the City of Cairns has a population only a quarter of that of Balikpapan. Finally, although there are very diverse uses around the inlet, little of this is in the form of heavy polluting industry. Nonetheless, the process of data collection, public participation and multiple use goals of management are extremely useful for comparison.

3. Moreton Bay, Southern Queensland

The physical features of Moreton Bay are again different to Balikpapan, but the heavy uses, with Brisbane, a city of a million people, situated on the Brisbane River, which enters into the bay. Moreton Bay is relatively open, partially protected by large sand masses of Moreton and Stradbroke Islands. A large number of estuaries enter into the bay and mangroves are extensive.

As with Port Curtis, there have been major concerns about the environment of Moreton Bay, and in 1989 the Australian Littoral Society and the Australian Marine Science Consortium held a symposium to highlight the issues (Crimp, 1992). Discussed are the physical and biological environments, socio-economics and pressures, and the management and future of the Bay.

Partly in response, the Queensland Government adopted a Strategic Plan in 1993, the essence of which was zoning for sustainable use. A copy of part of the plan is attached. Whilst only parts are relevant to Balikpapan the overriding vision:

> "to provide for ecologically sustainable use of Moreton Bay and to protect its natural, recreational, cultural heritage and amenity values"

would be appropriate with the aims and objections for each interest group sector being particularly relevant.

REFERENCES

Crimp, O.N. (ed.) 1992. *Moreton Bay in the Balance.* Proc. of Symp. organised by Austr. Litt. Soc. and Austr. Mar. Sci. Consort. 127pp.

Dept. Of Environment, Queensland 1993. Moreton Bay Strategic Plan.

4. Port of Townsville

Most of Australia's tropical ports have environmental officers and many have adopted environmental guidelines which would be very applicable to Balikpapan and its port activities. This writer is most familiar with the Port of Townsville and a paper provided by the environmental officers of the port is attached.

The Port of Townsville is located on Cleveland Bay which is largely sheltered from the prevailing south-easterlies. Nonetheless, extensive breakwaters are needed to provide safe berthing in contrast to Balikpapan. Mangroves are extensive around the eastern side of the bay and coral reefs fringe nearby Magnetic Island. Townsville is a city of 140,000 people and is in the process of developing a strategic plan with its twin city Thuringowa (1998). The area has heavy industry including copper and nickel refineries and the world's largest zinc refinery is under construction. Meat processing, and a range of other lighter industries are also located here. Nickel ore (and in future zinc) is imported through the port and raw sugar is a major export.

Attempts have been made to identify best practices for port authorities and the attached paper describes the environmental philosophy of the Port Authority.

REFERENCES

Townsville & Thuringowa City Councils, 1998. *Townsville - Thuringowa Strategy Plan: Managing Future Growth and Development.* 60pp.

Townsville Port Authority, 1997. Port Planning and Environmental Management. Port of Townsville Experiences. 16pp.

5. South Florida, USA

Although this area is subtropical rather than tropical, it does provide the world's largest example of attempted wetlands management. The Everglades are only part of this area which over the last 100 years has been severely affected by man, including major drainage schemes, soil loss, degradation of water quality, nutrient enrichment, contamination by pesticides and mercury, fragmentation of landscapes, invasion by exotic species and loss of or decline in populations of native species (McPherson and Halley, eds., 1996). The area provides an excellent example of environmental interactions and the complexity of many of the environmental problems.

The response is the South Florida Ecosystem Restoration Initiative, probably the largest holistic integrated coastal management project yet attempted. It was established in 1996 and the estimated cost for full restoration is US$7.8billion.

Whilst the scale of the project is unlikely to be repeated elsewhere, the identification of the sources of the problems, the processes of planning and at least some of the strategies being put in place may provide lessons for all scales of coastal management. A paper dealing with the initiative, though directed especially towards coral reefs was presented at the ITMEMS conference in Townsville in 1998 (Causey, 1998). Further reports and technical memoranda are expected.

REFERENCES

Causey, B.D. 1998. The role of the Florida Keys Marine Sanctuary in the South Florida Ecosystem Restoration Initiative. Paper presented to the ITMEMS conference, Townsville, Nov. 1998, 15pp.

McPherson, B.F. & Halley, R. (Eds.) 1996. *The South Florida Environment - A Region Under Stress.* U.S. Geol. Surv. Circ., 1134, 61pp.

APPENDIX C:

PLATES

Key to Erosion Index Abbreviations

vi	-	vegetation index
si	-	slope index
pi	-	pedology (soil) index
ri	-	rainfall index
hi	-	human structure index
E.I.	-	Erodability Index

APPENDIX D:

ACCOMPANYING STUDIES